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Charts for Interpreting Wildland Fire Behavior Characteristics

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RESEARCH SUMMARY

The fire characteristics chart is proposed as a graphical method of presenting two primary characteristics of fire behavior: spread rate and intensity. Its primary use is communicating and interpreting either site-specific predictions of fire behavior or National Fire-Danger Rating System (NFDRS) indexes and components. Rate of spread, heat per unit area, flame length, and fireline intensity are plotted on a fire behavior chart. Spread component, energy release component, and burning index are plotted on an NFDRS chart.

Specific examples illustrate use of a fire characteristics chart in conjunction with fire prescriptions, fire behavior forecasts, fire management plans, and briefings.

The equations used in creating the charts are given; and a method of obtaining heat per unit area from fire behavior nomograms is illustrated.

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FIRE CHARACTERISTICS CHARTS

A fire characteristics chart is a graph that illustrates the two primary characteristics of fire behavior—spread rate and intensity. Overall fire severity, as well as the character of the fire, can be inferred from the location of a point representing the fire on the chart. The chart is mainly useful as a communication aid. The fire characteristics chart can be used for site-specific predictions of fire behavior (fig. 1) or for National Fire-Danger Rating System (NFDRS) indexes and components (fig. 2).

There is a pressing need for analysis of fire behavior and a clear understanding of the analysis at all levels of management. Fire policy on National Forests has shifted emphasis from fire control to fire management. In addition to traditional fire control and use activities, a successful fire manager must also evaluate alternative fire management strategies in relation to land and resource management objectives. A vital part of this process is communication with other resource specialists who may not be familiar with the National Fire-Danger Rating System or methods for predicting site-specific fire behavior. Quantitative descriptors of fire behavior are becoming more widely used due to the prevalence of automated systems (Rothermel 1980). The hand-held TI-59 calculator with a Fire Danger/Fire Behavior Custom Read Only Memory (CROM) is an example of technology that is reaching every level of fire manager—from dispatchers to regional planners (Burgan 1980). Fire characteristics charts allow graphic presentation of quantitative fire behavior information in a form that is readily understood.

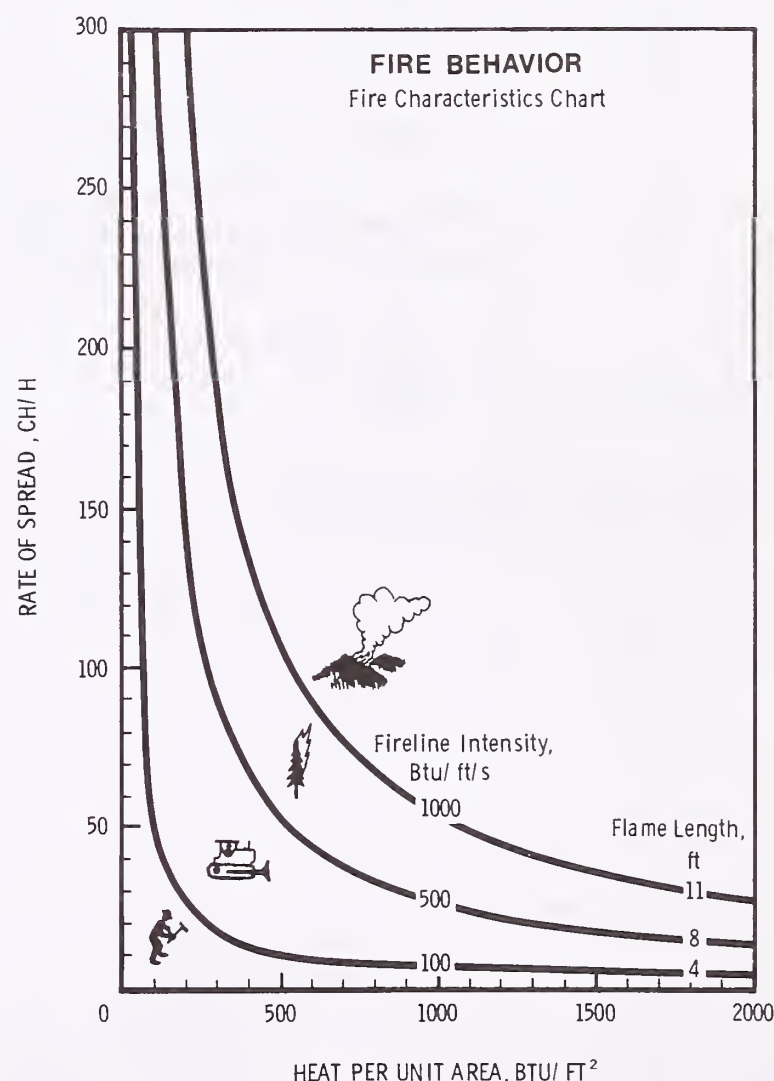


Figure 1.—Fire behavior fire characteristics chart.

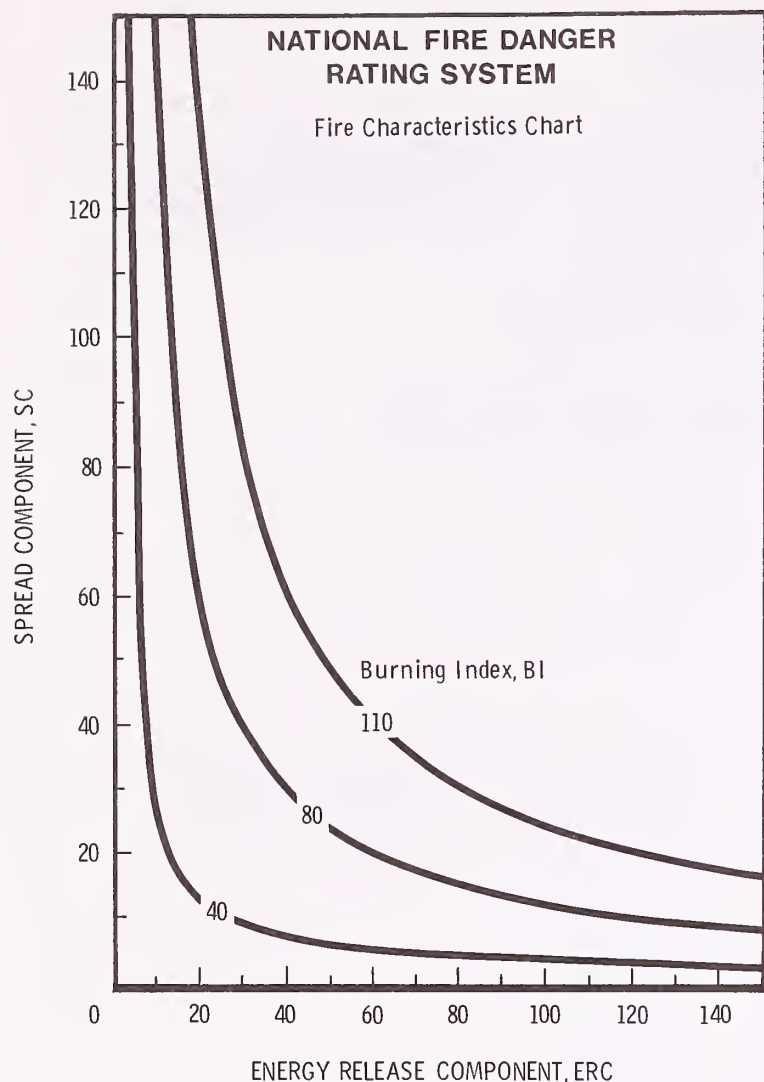


Figure 2.—National Fire-Danger Rating System (NFDRS) fire characteristics chart.

FIRE BEHAVIOR CHARTS

The values that are plotted on the fire behavior charts are based on a mathematical model for predicting fire spread in wildland fuels (Rothermel 1972). Calculations are made using nomograms (Albini 1976a), computer (Albini 1976b), or calculator (Burgan 1979). The model estimates actual fire behavior from specific descriptions of fuel type, fuel moisture, topography, and wind. The four descriptors of fire behavior that are plotted as a single point on the chart are:

1. Rate of spread (chains/hour), the forward rate of spread at the head of a surface fire.
2. Heat per unit area (Btu/ft^2), a measure of the amount of heat that is released by a square foot of fuel while the flaming zone of the fire is in that area. (Procedures for obtaining this value from nomograms and the equation for modifying existing computer programs are given in appendix A.)
3. Flame length (feet), the length of the flame at the head of the fire measured from the middle of the combustion zone to the average position of the flame tip. Flame length is determined by the rate of spread and the heat per unit area of the fire.
4. Fireline intensity ($\text{Btu}/\text{ft}/\text{s}$), the amount of heat released per second by a foot-wide slice of the flaming

combustion zone (Byram 1959). This value has been directly related to flame length, an observable characteristic of fire behavior. Fireline intensity is indicative of the heat that would be experienced by a person working near the fire.

Flame length and fireline intensity can be interpreted in terms of suppression capabilities as shown in table 1. The curved lines on the fire behavior chart define the areas of interpretations shown in table 1. The interpretations range from fires being easily controlled by hand crews, to fires on which equipment can be effective, to fires on which control effort at the head will be ineffective.

As an illustration of how the fire behavior chart works, the fire behavior prediction values listed in table 2 are plotted in figure 3. These predictions are for fires in three fuel types burning under the same wind, slope, and fuel moisture conditions. The fuel types were chosen from the 13 stylized fire behavior fuel models (Anderson 1982). Fuel model 1 represents continuous stands of arid western grass; fuel model 10, litter and understory of a timber stand with heavy accumulations of deadfall; and fuel model 8, short-needle litter.

The differences among the characteristics of the fires in these three fuel types are readily apparent from their

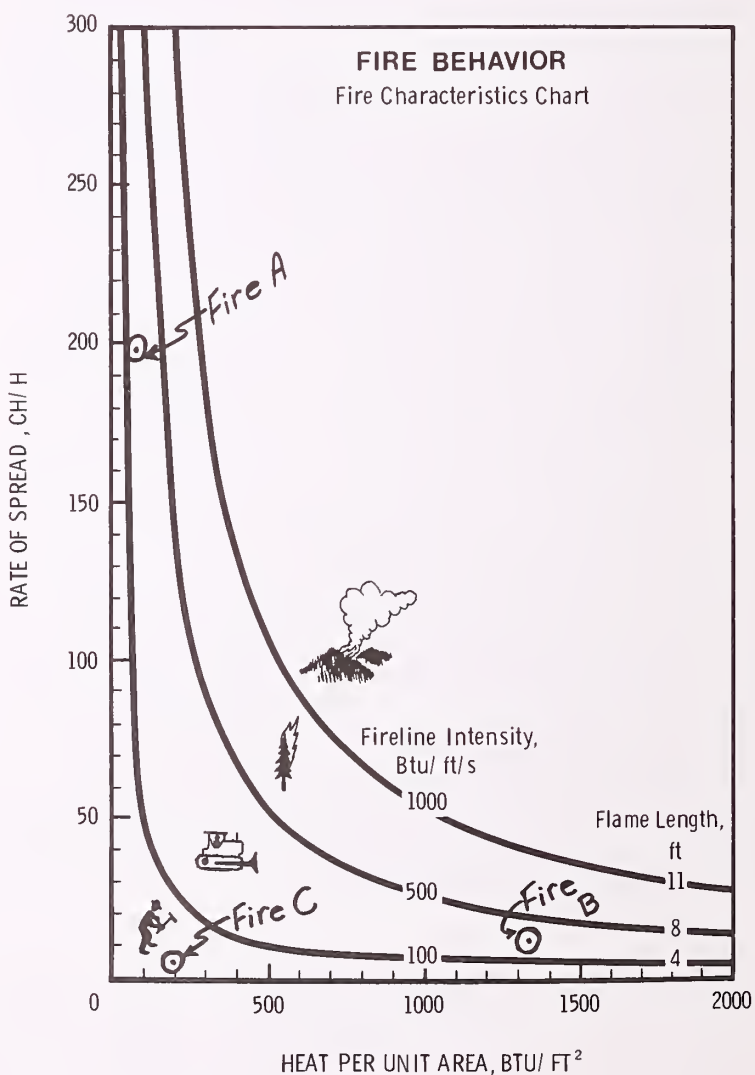


Figure 3.—Fire behavior predictions from table 2 plotted on a fire behavior chart.

Table 1.—Fire suppression interpretations of flame length and fireline intensity

Flame length	Fireline intensity	Interpretation
<i>Feet</i>	<i>Btu/ft/s</i>	
< 4	< 100	Fire can generally be attacked at the head or flanks by persons using handtools. Handline should hold the fire.
4-8	100-500	Fires are too intense for direct attack on the head by persons using handtools. Handline cannot be relied on to hold fire. Equipment such as plows, dozers, pumpers, and retardant aircraft can be effective.
8-11	500-1,000	Fires may present serious control problems—torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.
> 11	> 1,000	Crowning, spotting, and major fire runs are probable. Control efforts at head of fire are ineffective.

Table 2.—Fire behavior predictions for specific fuel, moisture, wind, and slope conditions

Descriptors	Fire		
	A	B	C
Fuel and environmental conditions:			
Fuel model	1	10	8
Dead fuel moisture, percent	5	5	5
Live fuel moisture, percent	100	100	100
Midflame windspeed, mi/h	7	7	7
Slope, percent	10	10	10
Fire behavior predictions:			
Rate of spread, chains/h	197	14	4
Heat per unit area, Btu/ft ²	92	1,330	200
Fireline intensity, Btu/ft/s	333	344	13
Flame length, ft	7	7	1

placement on the chart. Notice that flame length and fireline intensity are essentially the same for fires A and B. Fire A is very fast spreading and has a low heat per unit area. On the other hand, fire B is slow spreading, but has a high heat per unit area. Both fires A and B are predicted to be too intense for direct attack at the head by persons using handtools (table 1), but this degree of severity is caused by fires of very different character.

Fire C occurs under the same wind, slope, and fuel moisture conditions as fires A and B. But the handline should easily hold fire C, whereas plows, dozers, pumpers, or retardant would probably be required on fires A and B. Notice that the character of these three fires can be determined by a glance at the chart. The same information is on table 2, but is not as easily interpreted.

In general, fires with a high rate of spread and low heat per unit area are plotted near the upper end of the vertical axis, whereas fires with low rates of spread and high heat per unit area fall to the right, near the horizontal axis. Fires with both high spread rate and high values of heat per unit area will lie in the center of the graph far from the origin. The overall severity of the fire is shown by increasing flame length and fireline intensity curves.

Although a point on the chart represents the characteristics of a fire, a circle around the point would more appropriately indicate the probable range of fire behavior. The numbers used to characterize fire behavior are a best estimate based on a mathematical model, and are subject to the assumptions and limitations of that model as described by Rothermel (1972) and Albini (1976a). In addition, fire is inherently variable and cannot be uniquely described over an area. The circle around a point becomes larger with more nonuniform fuels, more variable wind, and increasing fire severity. There are no simple techniques for estimating the range of fire behavior characteristics caused by nonuniformities at this time.

Because several fire behavior characteristics are plotted as a single point and because it is easier to interpret illustrations than arrays of numbers, the fire behavior chart lends itself to many applications. The chart can be used to illustrate the fire management activities and associated fire characteristics listed below:

Project fires

- Expected fire behavior given as written narrative in the fire behavior forecast.
- Expected change in fire behavior that may accompany a forecasted weather change.
- Level of fire behavior considered in an escaped

fire analysis.

- Expected change in fire behavior with a change in fuel type.

Prescribed fire

- Fire characteristics required to achieve specific burn objectives.
- Fire behavior expected under a range of weather conditions.
- Behavior of an escaped fire.
- Conditions that will require using ignition patterns to draw the fire and produce the desired intensity.
- Behavior of strip fires—bracketed by plotting the behavior of a backing fire and a free-burning head fire.

Long-range planning

- Variation of fire behavior between planning units under the same weather conditions.
- Effect of a change in fuel type on fire behavior.

Application of Fire Behavior Charts

EXAMPLE: FIRE PRESCRIPTIONS

Successful prescribed burning requires planning. Fischer (1978) proposes a four-point fire use plan and report: treatment area and objectives, fire prescription,

Part 2 — Fire Prescription

2.1 Treatment Specifications

2.11 Desired Accomplishment

- Kill shrubs and trees <5" D.B.H. without killing the overstory of western larch.
- Expose mineral soils over 60% of the area
- Reduce duff by 86%.

2.12 Desired Fire Behavior

- The flame length must be less than 4 feet to ensure that less than 60% of the crowns will be scorched, therefore allowing the larch to survive.
- Due to discontinuity of fuels, a head fire with a flame length of at least 2 feet is required to achieve a uniform burn pattern.
- The flame length should be less than 4 feet to reduce the risk of torching and spot fires. The burn area is within a mile of some 2-year old logging slash. If a spot fire occurs in the slash, it will require pumpers and possibly retardant for control.
- Under the burning conditions that are required to meet desired duff reduction objectives, a free-burning, forward-spreading fire would make torching, crowning, and spotting probable. Strip headfires will be used to keep the fire behavior within the required range.

2.13 Required Environmental Conditions

Relative Humidity	— 20-30%
Temperature	— 70-80 F
Windspeed (midflame)	— N-NW — 3-7 mph
1-H Fuel Moisture	— 10-14%
10-H Fuel Moisture	— 12-14%
Live Fuel Moisture	— 75-125%
Duff Moisture	— 50%

Figure 4.—The fire prescription part of a fire use plan and report.

burning plan, and report. The fire prescription portion includes a section on fire behavior and associated environmental conditions desired to meet burn objectives.

Increasingly specific fire management objectives have created a need for more quantitative descriptions of fire behavior. Rate of spread described as fast or slow, or fire intensity as hot or cool, is often not adequate. The four values plotted on the fire characteristics chart describe aspects of fire behavior that are important in both fire control and fire effects considerations. Flame length and fireline intensity are directly related to the effectiveness of control forces. Many prescribed burns are conducted under conditions that produce flame lengths less than 3 feet. Rothermel and Deeming (1980) have suggested that fireline intensity be correlated to fire effects in the flames or in the convection column, and heat per unit area be correlated to fire effects near the base of the fire in the duff and litter. Fire behavior can be quantified on a fire characteristic chart without dwelling on tables and numbers. An example of a section of a fire use plan and report and the associated fire behavior chart are shown in figures 4 and 5.

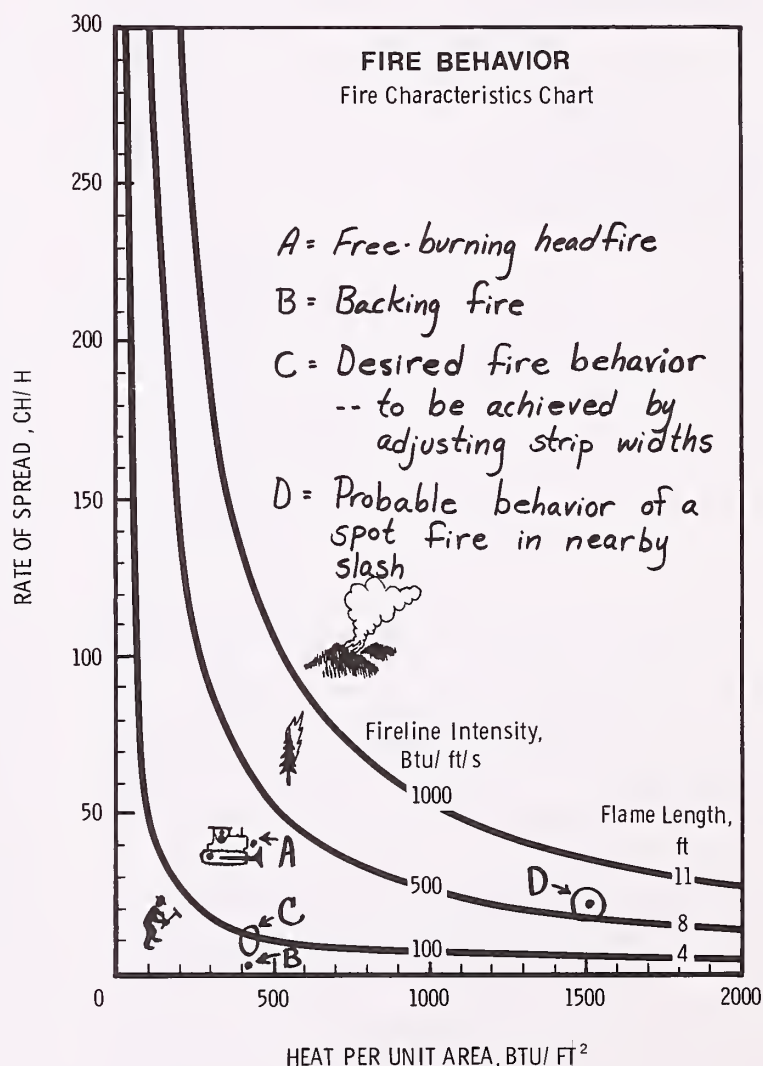


Figure 5.—Use of a fire characteristics chart to illustrate the desired fire behavior portion of the prescription given in figure 4.

EXAMPLE: FIRE BEHAVIOR FORECAST

A fire behavior officer (FBO) is normally part of an overhead team on a project fire. His duties include identifying critical fire behavior conditions and projecting fire size. He prepares a fire behavior forecast which includes a written narrative describing potential fire behavior. This is done for briefing the fire overhead team and is revised whenever conditions warrant a new appraisal of fire behavior. One of the tools the FBO uses in his job is the fire behavior model in the form of

nomograms or the TI-59 calculator. The numerical output from the model must be interpreted by the FBO before it is communicated. In addition to the narrative fire behavior forecast and a map indicating expected fire growth, a fire characteristics chart can be used in the oral briefing to illustrate potential fire behavior for different sectors of the fire. A fire behavior forecast and the associated fire characteristics chart are shown in figures 6 and 7.

FIRE BEHAVIOR FORECAST NO. _____	
NAME OF FIRE: _____	PREDICTION FOR: _____ Day _____ SHIFT
FOREST: _____	SHIFT DATE: _____
TIME AND DATE FORECAST ISSUED: _____ 0900	SIGNED: _____ FIRE BEHAVIOR OFFICER

.....

WEATHER SUMMARY RED FLAG ALERT SEE ATTACHED SPOT FORECAST.

Note Terrain channeling of the general wind up the river will produce up-canyon winds of 5 to 10 mi/h along the lower slopes and 10 to 15 mi/h along upper slopes by early afternoon.

FIRE BEHAVIOR

GENERAL: Fire will be relatively inactive until the inversion breaks, about 1200. Fire activity will increase sharply at that time with fire spread mainly up-canyon to the southwest. Some torching will occur where fuel concentrations exist with short range spotting possible.

SPECIFIC:

SECTOR A. Fire spread will be relatively low on this sector (3 chains per hour), but rolling fire-brands will be a problem, especially in the small draws to the south. Roll into unburned fuels will result in upslope runs with some torching and short range spotting.

SECTOR B. This will be a hot sector on the fire today. Direct attack with hand crews will be marginal until 1100 and impossible after the inversion breaks. Roll and spotting will cause short runs to the ridge, especially in the small draws to the south.

SECTOR C. The fire will back slowly down canyon against the wind. Rolling material may cause some problems, but this will be the coolest sector on the fire. Conditions will be good for direct attack to succeed.

AIR OPERATIONS: Strong inversion will limit air operations until about noon. Any thunderstorms that occur later in the day will produce turbulent flying conditions.

SAFETY: Crews should be alert to the danger of roll igniting fuels below them on steep slopes.

If thunderstorms enter the fire area, be alert for the possibility of erratic fire behavior from down-draft winds. A weather watch has been established to give warning of approaching thunderstorms.

Figure 6.—Fire behavior forecast.

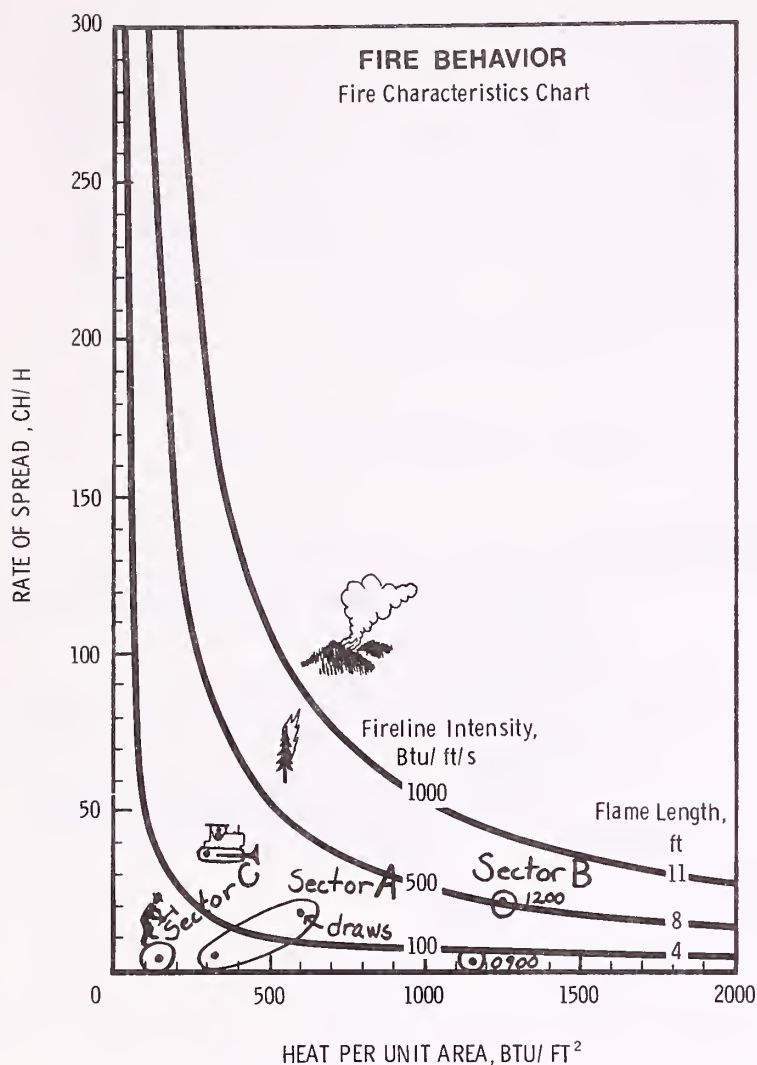


Figure 7.—Use of a fire characteristics chart to illustrate the fire behavior given in the fire behavior forecast in figure 6.

NATIONAL FIRE-DANGER RATING SYSTEM CHARTS

The National Fire-Danger Rating System (NFDRS) (Deeming and others 1977) is used throughout the country for fire management planning. Most users obtain daily ratings using a centralized computer (Helfman and others 1980); some use nomograms (Burgan and others 1977), or the TI-59 calculator with a fire danger/fire behavior CROM (Burgan 1979). Management guidelines are often based on indexes obtained by processing historical weather records through standard computer programs (Main and others in press; Bradshaw and Fischer 1981a, 1981b).

The NFDRS is comprised of many components and indexes related to fire occurrence, fire behavior, and fire suppression. The following items can be plotted on a fire characteristics chart similar to the one used for site-specific fire behavior estimation:

1. Spread component (SC)—related to rate of fire spread.
2. Energy release component (ERC)—related to energy or heat that will be released in a passing fire front.

3. Burning index (BI)—related to the magnitude of the fire containment problem. The burning index is derived from the spread component and the energy release component.

The three values are related to the corresponding values on the fire behavior-fire characteristics chart. Procedures used to calculate spread component, energy release component, and burning index were in fact derived from the equations for rate of spread, heat per unit area, and flame length. NFDRS indexes and components are designed to give broad area rating of fire potential and are not meant to predict actual site-specific fire behavior. The indexes are based on fuel models that describe large areas and on weather taken at a specific location once per day.

Because NFDRS components and indexes are relative indicators of fire danger, a value is meaningful only when it is compared with other values. Seasonal plots illustrated in figure 8 help one make such comparisons. An index value can be readily related to previous values in the season or, if plots are overlaid, to those from other seasons. As can be seen in figure 8, ERC had climbed to the highest point thus far that season by August 3, and did not change on August 4. However, SC for August 4 was four times as high as that on August 3, and BI nearly doubled from August 3 to August 4. Notice also that on October 3, BI was approximately the same as it had been on August 3, but SC was much higher and ERC much lower.

The fire characteristics chart offers another means of interpreting SC, ERC, and BI in terms of potential fire behavior. The values for August 3, August 4, and October 3 are plotted on the NFDRS chart in figure 9. The curved lines on the fire characteristics chart correspond to the horizontal lines on the seasonal plot of burning index. Notice how the character of fire danger on all 3 days is readily apparent.

The seasonal plots and the fire characteristics chart illustrate different aspects of SC, ERC, and BI. A seasonal plot reflects the change of conditions in a component or index over time, whereas the NFDRS chart is best suited for illustrating the relationship among all three values at a particular time.

NFDRS calculations are normally done on a day-to-day basis using standard weather observations as input. The TI-59 calculator with a fire danger/fire behavior CROM allows another option: fuel moisture can be entered directly in lieu of weather input. This allows the user to look at situations that are not based on the seasonal trend. For example, "under the same conditions, how does the fire danger change with a change of fuel models?" or "what would the fire danger be if the moisture content of the large fuels were 3 percent less?" The NFDRS chart is an ideal way of illustrating the change in fire danger due to a specific change in conditions.

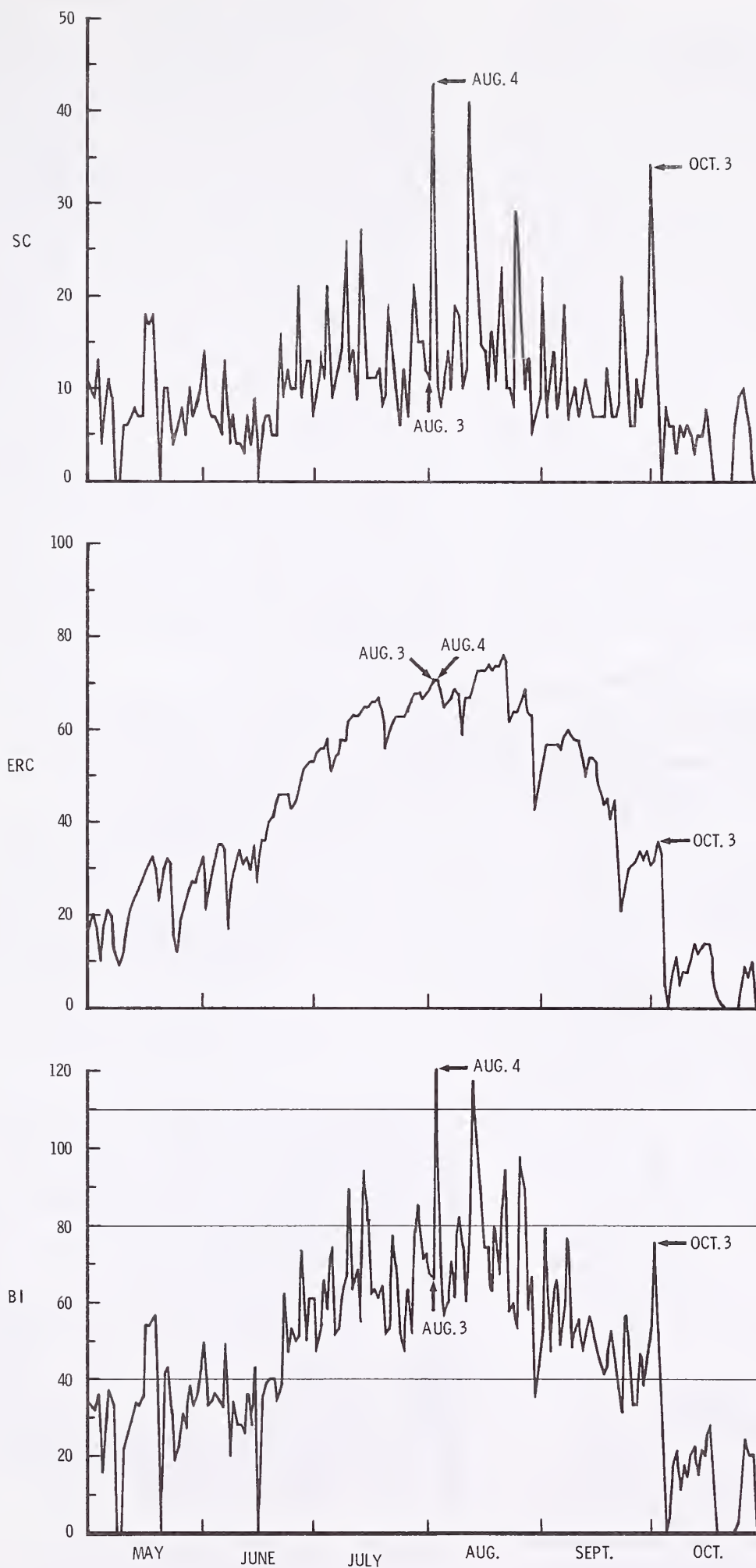


Figure 8.—Seasonal plots of spread component (SC), energy release component (ERC), and burning index (BI).

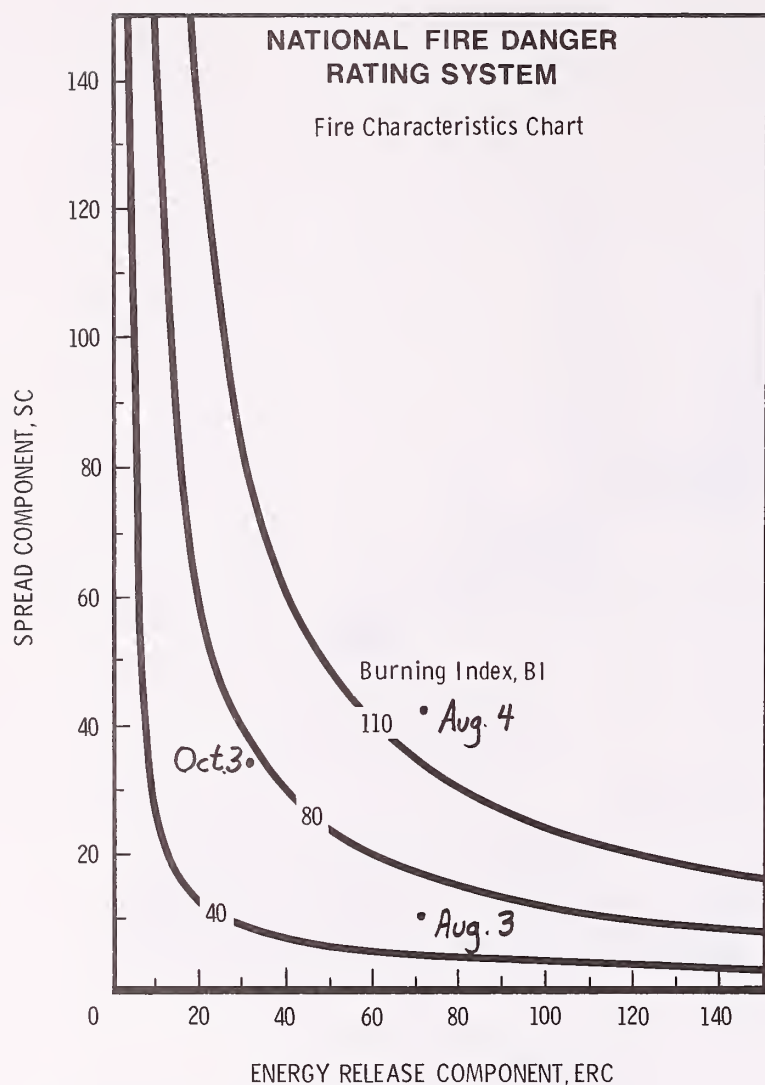


Figure 9.—SC, ERC, and BI for August 3, August 4, and October 3 from the seasonal plots in figure 8 plotted on an NFDRS chart.

A review of each index and the relationship between them will clarify the use of the NFDRS chart. Spread component is related to the rate of fire spread and is strongly affected by windspeed; SC can therefore have wide daily fluctuations. On the other hand, windspeed has no effect on energy release component. ERC is related to the energy released in the flaming zone and mainly reflects changes in fuel moisture. Because ERC is not affected by wind, it shows a more definite seasonal trend than either SC or BI. Burning index is derived from the spread and energy release components and has the same underlying trend as ERC with the daily fluctuations of SC imposed on it. Depending on the type of management decisions to be made, SC, ERC, BI, or a combination of these values can be used.

Application of NFDRS Charts

EXAMPLE: FIRE MANAGEMENT PLANS

USDA Forest Service fire management policy currently recognizes two categories of fires on its lands: wildfires and prescribed fires. Every wildfire requires an appropriate suppression response. Every prescribed fire is to be conducted in compliance with an approved plan. Unplanned ignitions can be allowed to burn as prescribed fires as long as they meet criteria established in approved fire prescriptions.

The Troy Ranger District in northwestern Montana prepared a fire management plan that covered the entire district. The plan was approved in early 1979, and several unplanned ignitions were used as prescribed fires that summer. A fire management prescription covers each of five fire management categories. Figure 10 is a flowchart for managing fires on big-game spring and winter ranges on operational fire management areas. Among the conditions that must be satisfied for a fire to be allowed to burn in these areas are limits on burning index and energy release component. The shaded area of the NFDRS chart in figure 11 illustrates these limits. If the plotted points from the last 4 days fall to the left of the vertical line where $ERC = 30$, and if the current day's point and the point forecasted for the next day fall in the smaller area limited by $BI = 28$, then the portion of the fire prescription based on the National Fire-Danger Rating System is satisfied.

As the fire season progresses, current information on weather, fire danger, fire activity, and prescription criteria must be readily available, as illustrated in figure 12. The NFDRS chart is a visual aid that clearly illustrates the limits determined from the National Fire-Danger Rating System.

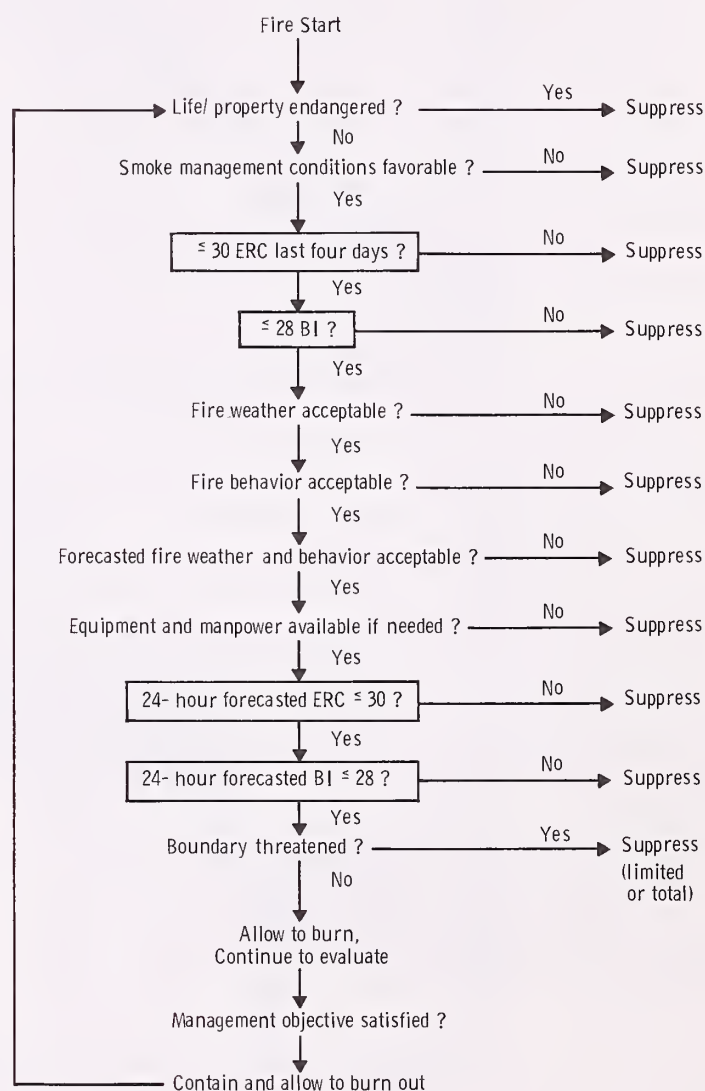


Figure 10.—Example flow chart for managing fires on big-game spring and winter ranges on operational fire management areas.

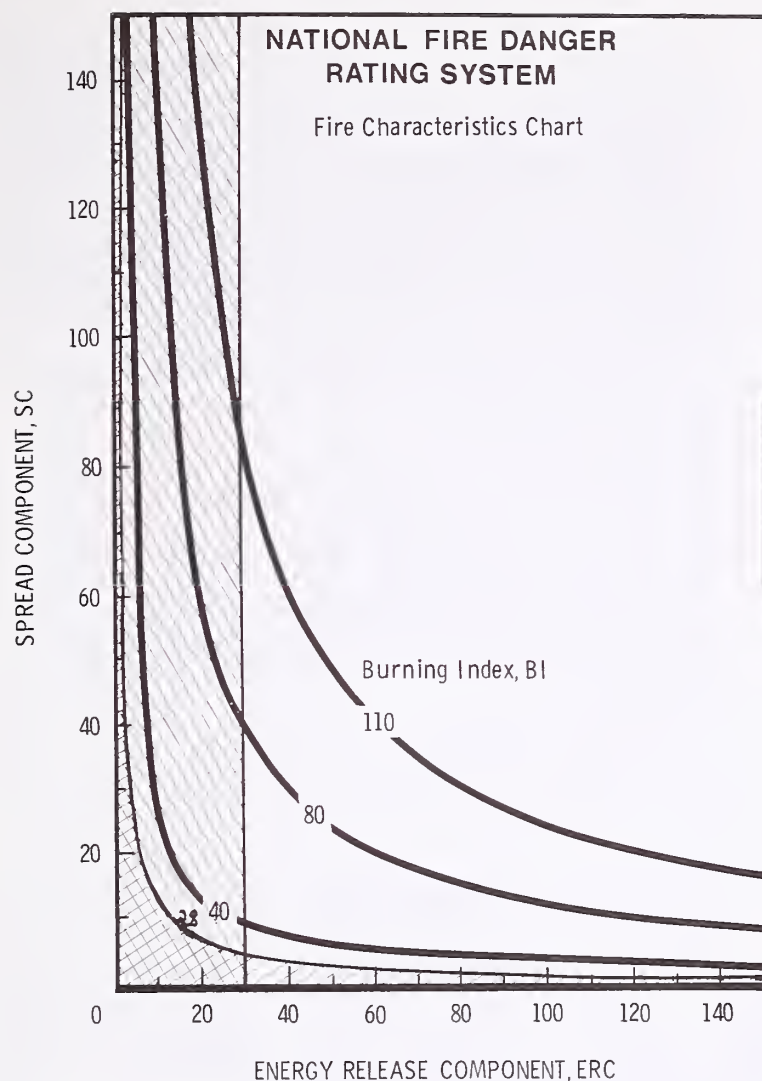


Figure 11.—NFDRS chart used to illustrate the limits on BI and ERC given in the flow chart in figure 10. For the portion of this fire prescription that is based on NFDRS indexes to be satisfied, plotted points from the last 4 days must fall to the left of the vertical line where ERC = 30 and the current day's point and the point forecasted for the next day must fall in the smaller area limited by the BI = 28 line.

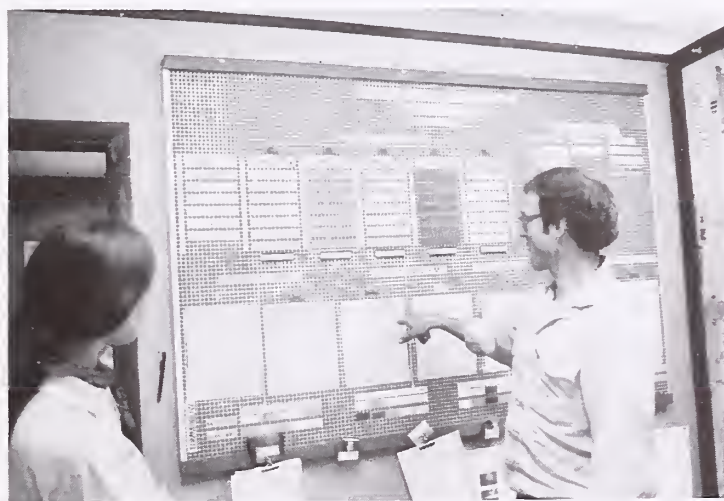


Figure 12.—The fire characteristics chart can be part of a display that includes current information on weather, fire danger, fire activity, and prescription criteria that a fire manager uses to make decisions.

EXAMPLE: BRIEFINGS

During the fire season, briefings are often held to describe the general fire situation. The audience can include members of the news media, staff personnel, or others who are not familiar with the National Fire-Danger Rating System. Statements such as "the fire danger is high" or "the burning index is 85" can be misinterpreted. The NFDRS chart can serve as a visual aid and focal point for discussion. The chart can be explained easily: as a point falls farther to the right on the chart, there is an indication that fires will be hotter. A point falling farther up on the chart indicates the potential for faster spreading fires. Overall severity increases as a point falls farther from the origin in either direction.

Consider the following briefing of fire danger of a USDA Forest Service region, represented by the fire characteristics chart in figure 13.

The fire danger of most of the west side of the region is low as indicated by point A, although there are a couple of districts that may cause problems (point B). Point C refers to the fire danger on the east side of the region. If we have another week of dry weather, the situation on the east side could become critical (point D).

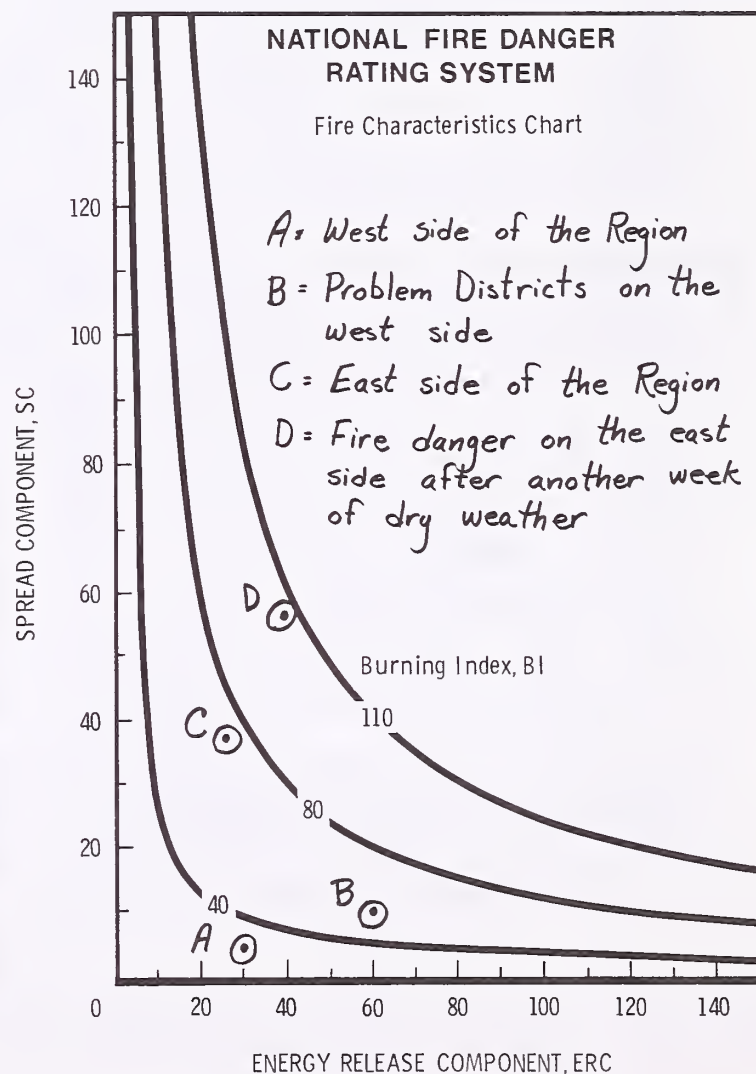


Figure 13.—NFDRS chart used in a briefing of current and potential fire danger.

FORMS OF THE CHART

The fire behavior chart and the NFDRS chart illustrated in figures 1 and 2 have scales that do not cover the entire range of possible values. The scales were chosen to give resolution to the lower values and allow the majority of values to be plotted on the chart. Nevertheless, some points will fall beyond the limits of the graph. A form of the fire behavior chart that overcomes this limitation uses logarithmic scales on the axes. In this way the entire range of values can be covered. The curved flame length lines become straight lines on the log scale version of the chart.

Figure 14 shows six points plotted on both linear and logarithmic scale fire behavior charts. This illustrates that a relatively small change in the behavior of a low-intensity fire is amplified, and a large change in the behavior of a high-intensity fire is compressed on the logarithmic chart. Because a primary purpose of the fire characteristics chart is to visually illustrate changes in fire behavior, care should be taken in interpretation of relative location of points plotted on the logarithmic chart.

It may be necessary to change the scales of a chart primarily used for a specific fuel type. For example, a chart primarily used to display fire behavior predictions in logging slash should have an expanded heat-per-unit-area axis and a truncated rate-of-spread axis. Such a chart is shown in appendix B, along with other full-size charts suitable for reproduction. Appendix A offers the equations used in creating the fire characteristics charts.

An NFDRS chart can illustrate NFDR Manning classes for a specific area. USDA Forest Service fire specialists generally determine manning classes from the 90th and 97th percentile burning index values for a specific station and fuel model. The percentile values are determined from historical fire weather observations and provide criteria for ranking the relative severity of the burning conditions on a given day. Appendix A includes an example showing how to design an NFDRS chart where BI lines designate manning class levels.

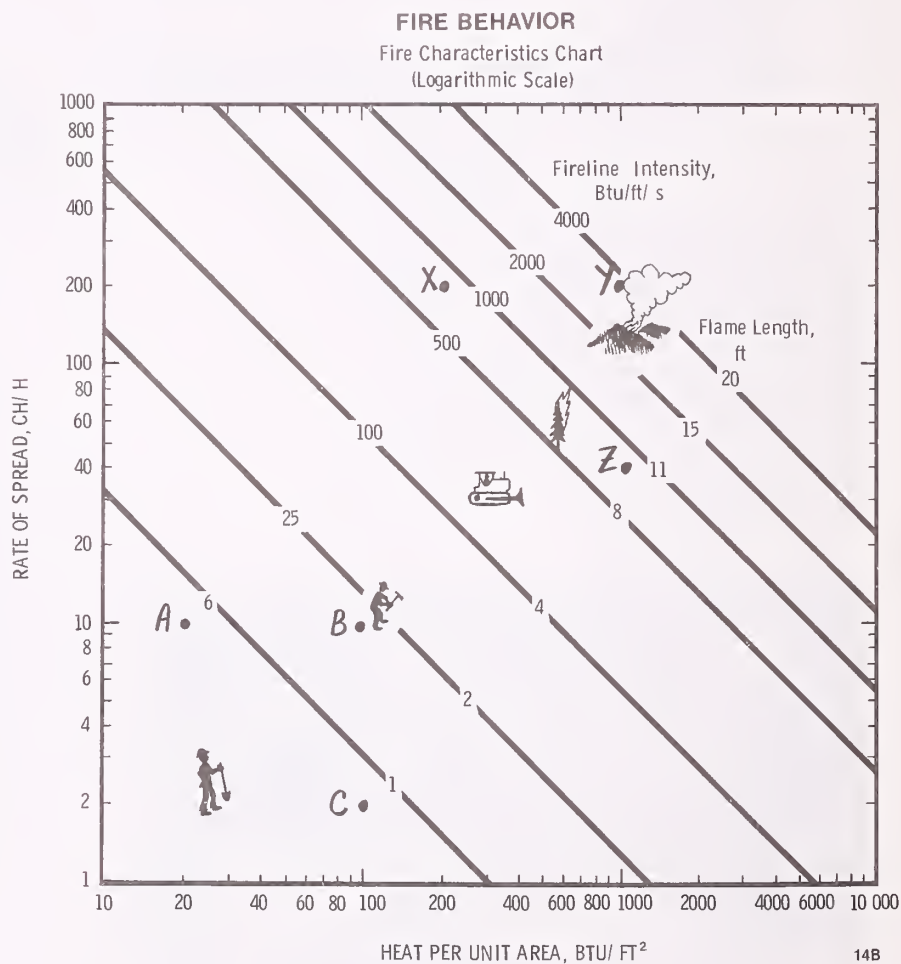
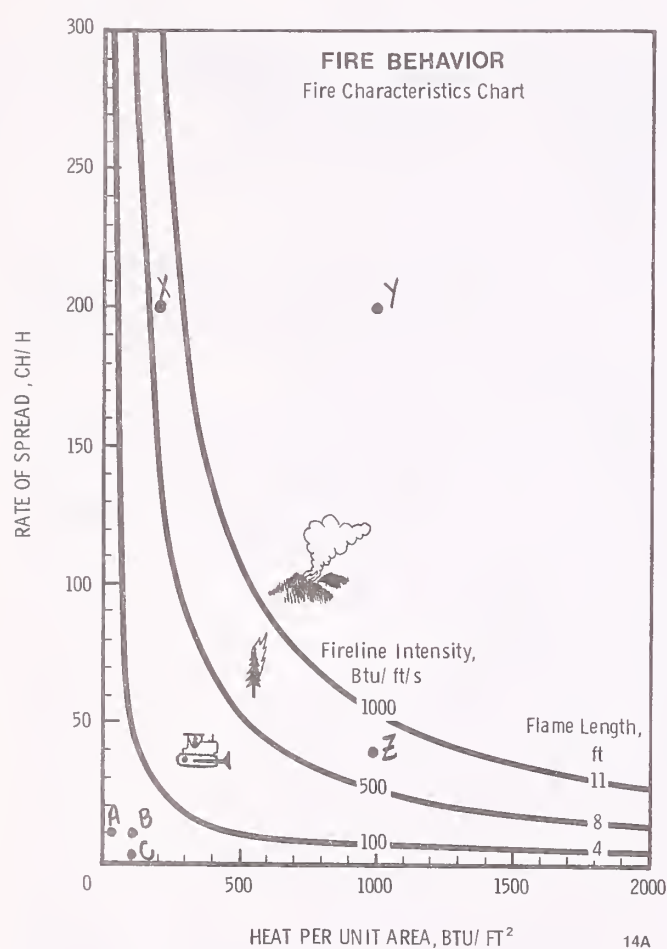


Figure 14.—The same six points (A, B, C, X, Y, Z) plotted for comparison on both a linear scale (A) and a logarithmic scale (B) fire behavior chart.

SUMMARY

Fire characteristics charts can be used to plot either site-specific fire behavior predictions or National Fire-Danger Rating System indexes. Because several aspects of fire behavior are plotted as a single point, the chart aids a user in assessing overall fire characteristics. The chart lends itself to a wide range of potential uses, the most significant being communication of quantitative values in a form that is easily understood.

PUBLICATIONS CITED

- Albini, Frank A. Estimating wildfire behavior and effects. Gen. Tech. Rep. INT-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976a. 92 p.
- Albini, Frank A. Computer-based models of wildland fire behavior: a user's manual. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976b. 68 p.
- Anderson, Hal E. Heat transfer and fire spread. Res. Pap. INT-69. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 20 p.
- Anderson, Hal E. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 22 p.
- Bradshaw, Larry S.; Fischer, William C. A computer system for scheduling fire use. Part I: the system. Gen. Tech. Rep. INT-91. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981a. 63 p.
- Bradshaw, Larry S.; Fischer, William C. A computer system for scheduling fire use. Part II: computer terminal operator's manual. Gen. Tech. Rep. INT-100. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981b. 33 p.
- Burgan, Robert E.; Cohen, Jack D.; Deeming, John E. Manually calculating fire-danger ratings—1978 National Fire-Danger Rating System. Gen. Tech. Rep. INT-40. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 49 p.
- Burgan, Robert E. A handheld calculator—fire danger and fire behavior. *In: Sixth conference on fire and forest meteorology: proceedings; 1980 April 22-24; Seattle, WA. Washington, DC: Society of American Foresters; 1980: 65-69.*
- Burgan, Robert E. Fire danger/fire behavior computations with the Texas Instruments TI-59 calculator: user's manual. Gen. Tech. Rep. INT-61. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 25 p.
- Byram, G. M. Combustion of forest fuels. *In: Forest fire: control and use. Edited by K. P. Davis. McGraw-Hill, New York, 1959. pp. 61-89.*
- Deeming, John E.; Burgan, Robert E.; Cohen, Jack D. The national fire-danger rating system—1978. Gen. Tech. Rep. INT-39. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 63 p.
- Fischer, William C. Planning and evaluating prescribed fires—a standard procedure. Gen. Tech. Rep. INT-43. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1978. 19 p.
- Helfman, Robert S.; Straub, Robert J.; Deeming, John E. User's guide to AFFIRMS: time share computerized processing of fire danger rating. Gen. Tech. Rep. INT-82. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 150 p.
- Main, William A.; Straub, Robert J.; Paananen, Donna M. FIREFAMILY: fire planning with historic weather data. Gen. Tech. Rep. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest and Range Experiment Station; in press.
- Rothermel, Richard C. How to predict the spread and intensity of forest and range fires. Gen. Tech. Rep. INT- . Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. In preparation.
- Rothermel, Richard C. A mathematical model for predicting fire spread in wildland fuels. Res. Pap. INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 40 p.
- Rothermel, Richard C. Fire behavior systems for fire management. *In: Sixth conference on fire and forest meteorology: proceedings; 1980 April 22-24; Seattle, WA. Washington, DC: Society of American Foresters; 1980: 58-64.*
- Rothermel, Richard C.; Deeming, John E. Measuring and interpreting fire behavior for fire effects. Gen. Tech. Rep. INT-93. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 3 p.

APPENDIX A

Equations for Compiling the Fire Characteristics Charts

The equation used to plot the curves on the NFDRS chart is

$$SC = \frac{0.091 \times BI^{2.17}}{ERC} \quad (1)$$

where

SC = spread component
ERC = energy release component
BI = burning index.

The equation used to plot the curves on the fire behavior chart

$$R = \frac{55 I_B}{H_A} \quad (2)$$

where

R = rate of spread, chains/h
 I_B = fireline intensity, Btu/ft/s
 H_A = heat per unit area, Btu/ft².

The relationship between fireline intensity and flame length is given by the following equation:

$$F_L = 0.45 I_B^{0.46} \quad (3)$$

where

F_L = flame length, ft
 I_B = fireline intensity, Btu/ft/s.

Determination of Heat Per Unit Area

Heat per unit area is a direct output of the TI-59 fire behavior program. However, it cannot be read directly from the nomograms, nor is it an output value from most available computer programs. Although a point can be plotted on the fire behavior chart given rate of spread and fireline intensity or flame length, it is easier if a heat per unit area value is available.

To modify an existing computer program, use a reformulation of equation (2)

$$H_A = \frac{55 I_B}{R} \quad (4)$$

where

H_A = heat per unit area, Btu/ft²
 I_B = fireline intensity, Btu/ft/s
R = rate of spread, chains/h.

The X axis of the upper right-hand graph of the nomograms as originally published by Albini (1976a) is reaction intensity (Btu/ft²/min). The label was eliminated on subsequent revisions for fire behavior officer (FBO) training. The nomograms to be published by Rothermel (in preparation) will have heat per unit area on that axis.

The relationship between reaction intensity and heat per unit area is

$$H_A = I_R \frac{384}{\tilde{\sigma}}$$

where

H_A = heat per unit area, Btu/ft²
 I_R = reaction intensity, Btu/ft²/min
 $\tilde{\sigma}$ = characteristic surface-area-to-volume ratio of the fuel array, ft²/ft³
 $\frac{384}{\tilde{\sigma}}$ = residence time, min (Anderson 1969).

The labels for heat per unit area can be added to the horizontal axis on the upper right-hand quadrant of the nomograms, using the scales given in figure 15. The scale is the same for both the low and high windspeed options on all versions of the nomograms. Use of the nomograms does not change, as illustrated in the example in figure 16. Heat per unit area is read where the first constructed vertical line intersects the newly labeled axis.

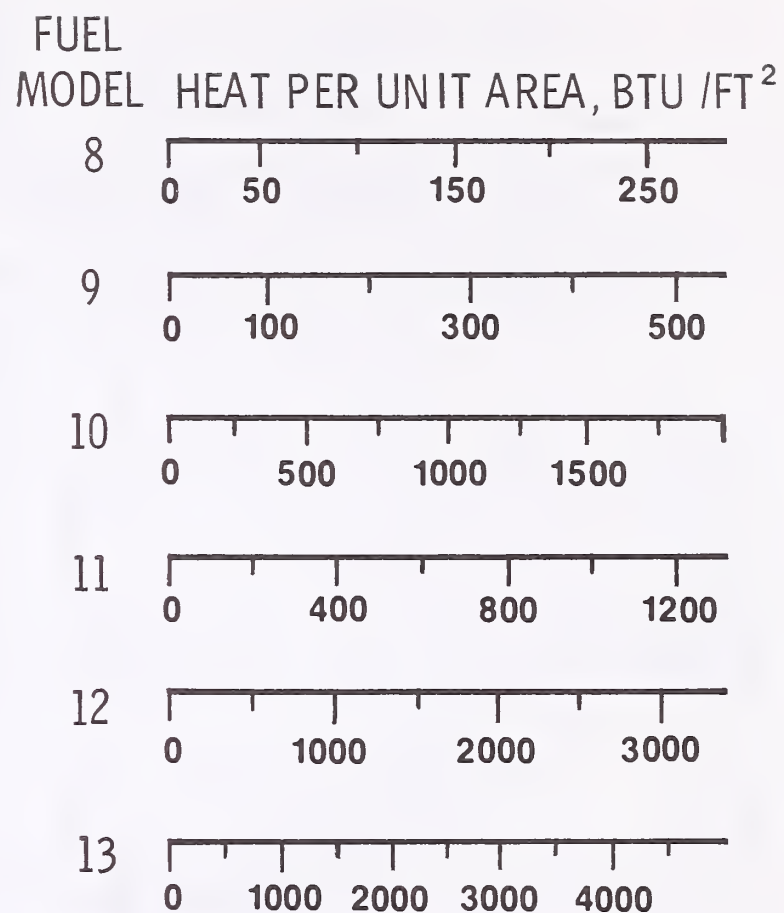
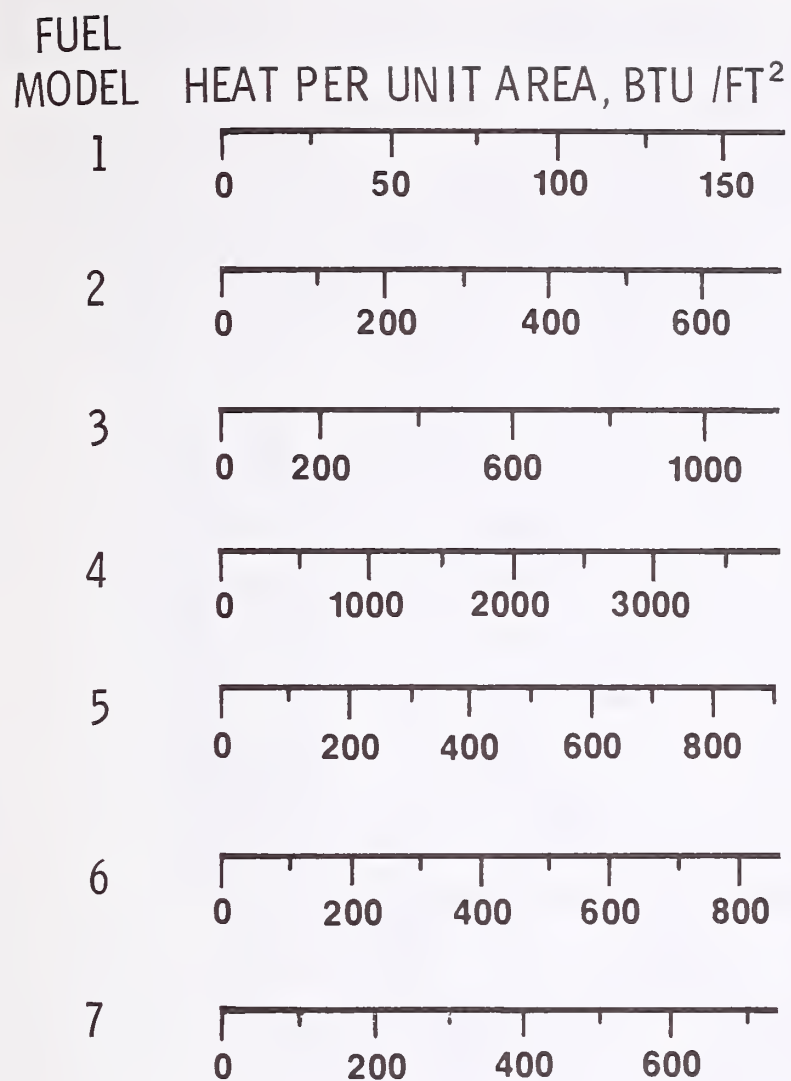
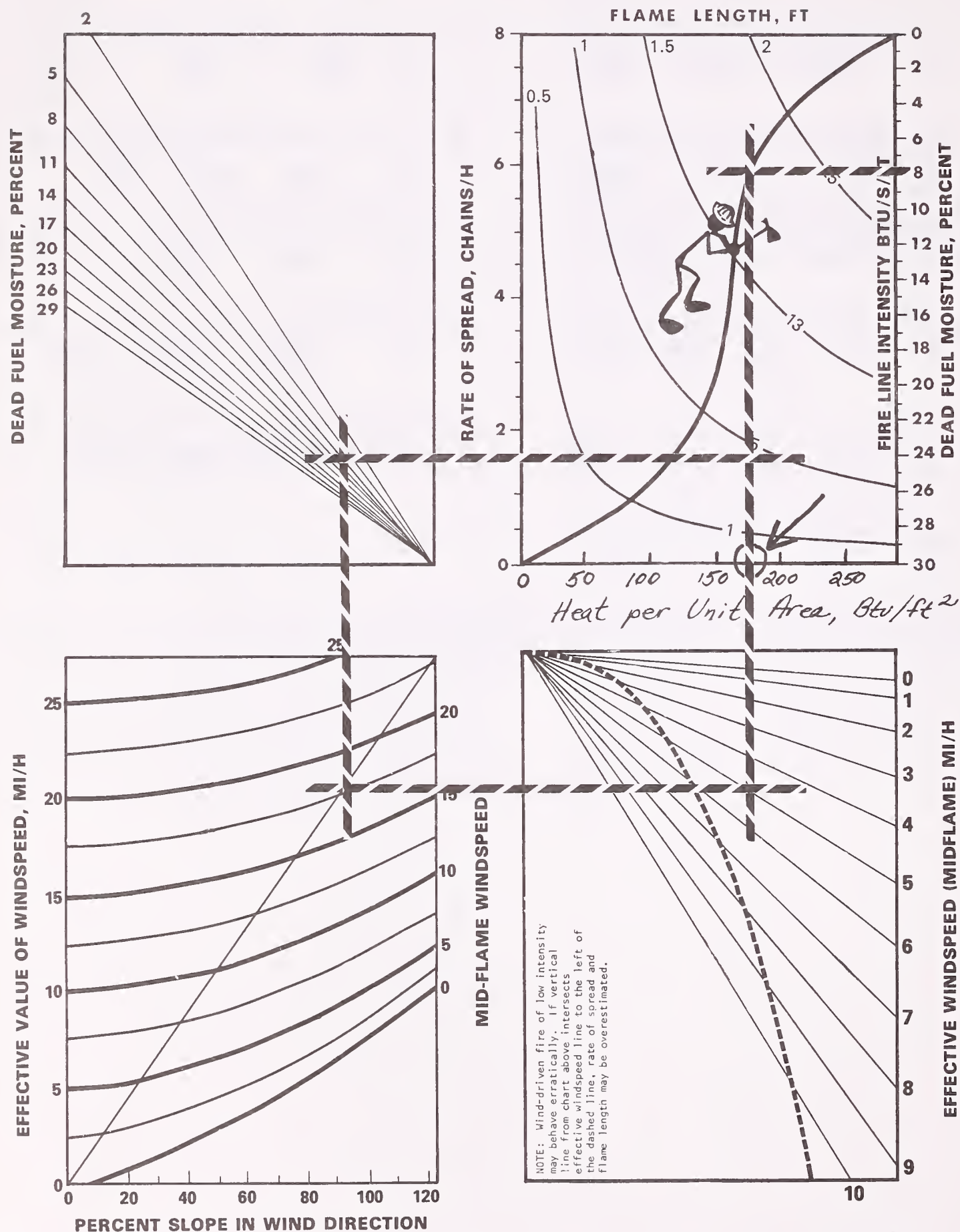


Figure 15.—Heat-per-unit-area scales can be transferred to the high or low windspeed options of the fire behavior nomograms (FBO or Albini 1976a). The scale for the appropriate fuel model is transferred to the horizontal axis of the upper right-hand graph.

Input:
 Fuel Model 8
 Dead fuel moisture = 8%
 Effective windspeed = 5 mi/h

Output:
 Rate of spread = 1.75 chains/h
 Flame length = 1 ft.
 Fireline intensity = 5 Btu/ft/s
 Heat per unit area = 175 Btu/ft²

8. CLOSED TIMBER LITTER - LOW WINDSPEEDS



May, 1978

Figure 16.—Example of the use of a nomogram after the heat-per-unit-area label has been transferred from figure 15.

Creation of a Custom NDFRS Chart

An example of a custom NFDRS chart is shown in figure 17. This chart is for the Ninemile District (Lolo National Forest), fuel model G. Manning classes are based on burning index.

The steps to creation of such a chart are as follows:

1. Run the FIRDAT program as described in the User's Guide to FIREFAMILY (Main and others in press) to determine the 90th and 97th percentile values of BI and the maximum SC and ERC values.

For this example, based on the 1970-79 weather data, the 90th percentile of BI is 56.38 and the 97th percentile is 69.74. The maximum SC for this period was 49 and the maximum ERC was 60.

2. Calculate the manning class boundary values as described in the User's Guide to AFFIRMS (Helfman and others 1980).

For six manning classes in this example, the results are:

Displayed manning class	Upper value for class (burning index)	
1	¹ (MI90)/4	= 14
2	(MI90)/2	= 28
3 -	(MI90)(3/4)	= 42
3 +	(MI90)	= 56
4	MI97	= 70
5	More than MI97	

¹This notation corresponds to that used in the AFFIRMS manual. MI90 = 90th percentile manning index and MI97 = 97th percentile manning index.

3. Draw the axes for the chart based on the maximum values for SC and ERC.

In this case, the axes are extended beyond the 10-year maximums to SC = 60 and ERC = 70.

4. Locate the curves for each of the BI values determined in step 2 above using equation (1). Find SC for several values of ERC. The upper endpoints of the BI curves can most easily be located by using an alternate form of equation (1):

$$ERC = \frac{0.091 \times BI^{2.17}}{SC}$$

To locate the BI = 56 curve in figure 17, find ERC when SC = 60 (the maximum SC for this chart):

$$ERC = \frac{0.091 \times 56^{2.17}}{60} = 9.4$$

Find the other endpoint of the curve by calculating SC when ERC = 70 (the maximum ERC for this chart):

$$SC = \frac{0.091 \times 56^{2.17}}{70} = 8$$

Similarly when ERC = 40 and 20, the calculated values for SC are 14 and 28, respectively. A smooth curve is drawn through the following four points:

ERC	SC
9	60
20	28
40	14
70	8

The curves for the other manning class divisions (BI = 14, 28, 42, and 70) are located in a similar manner.

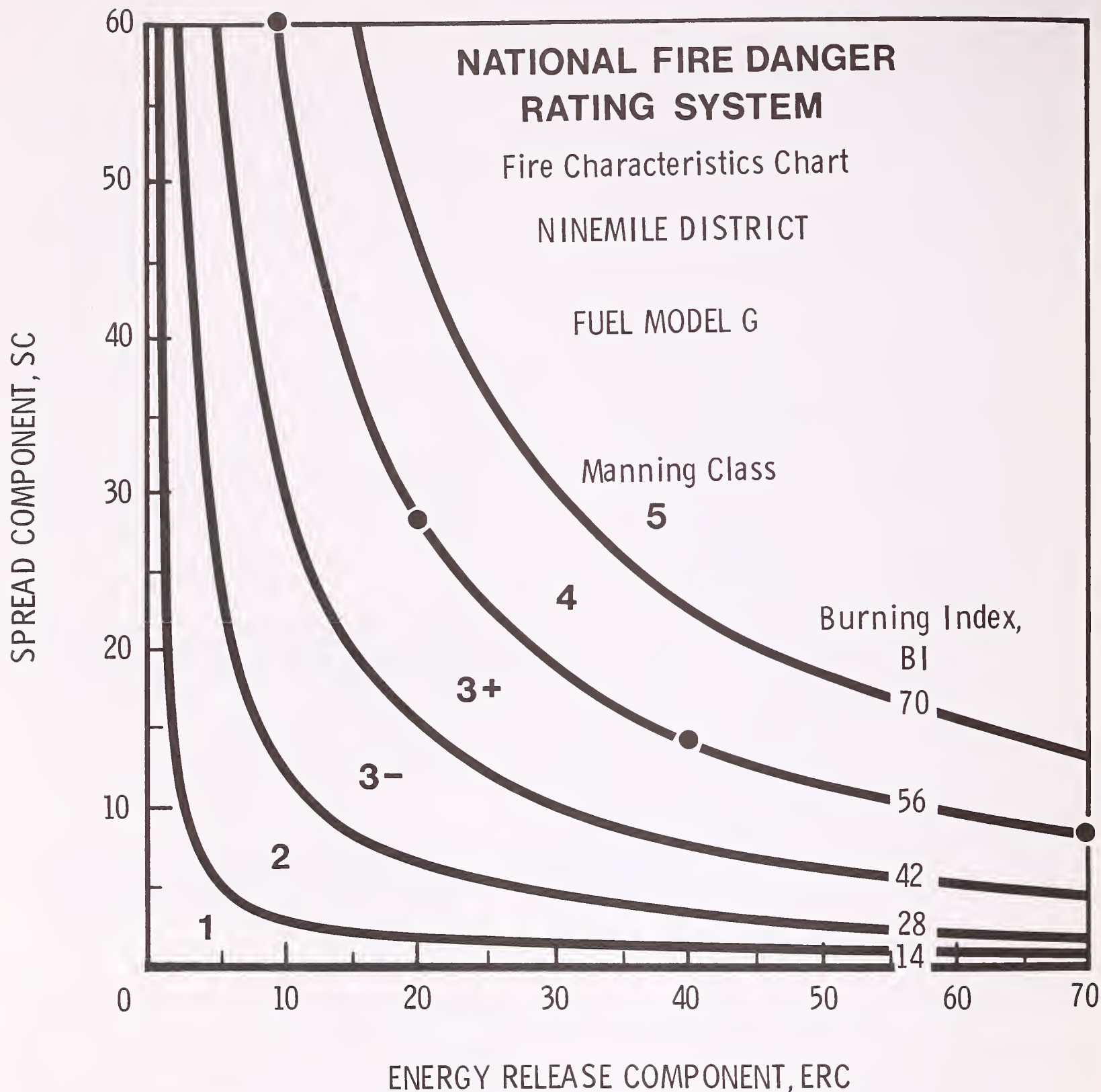
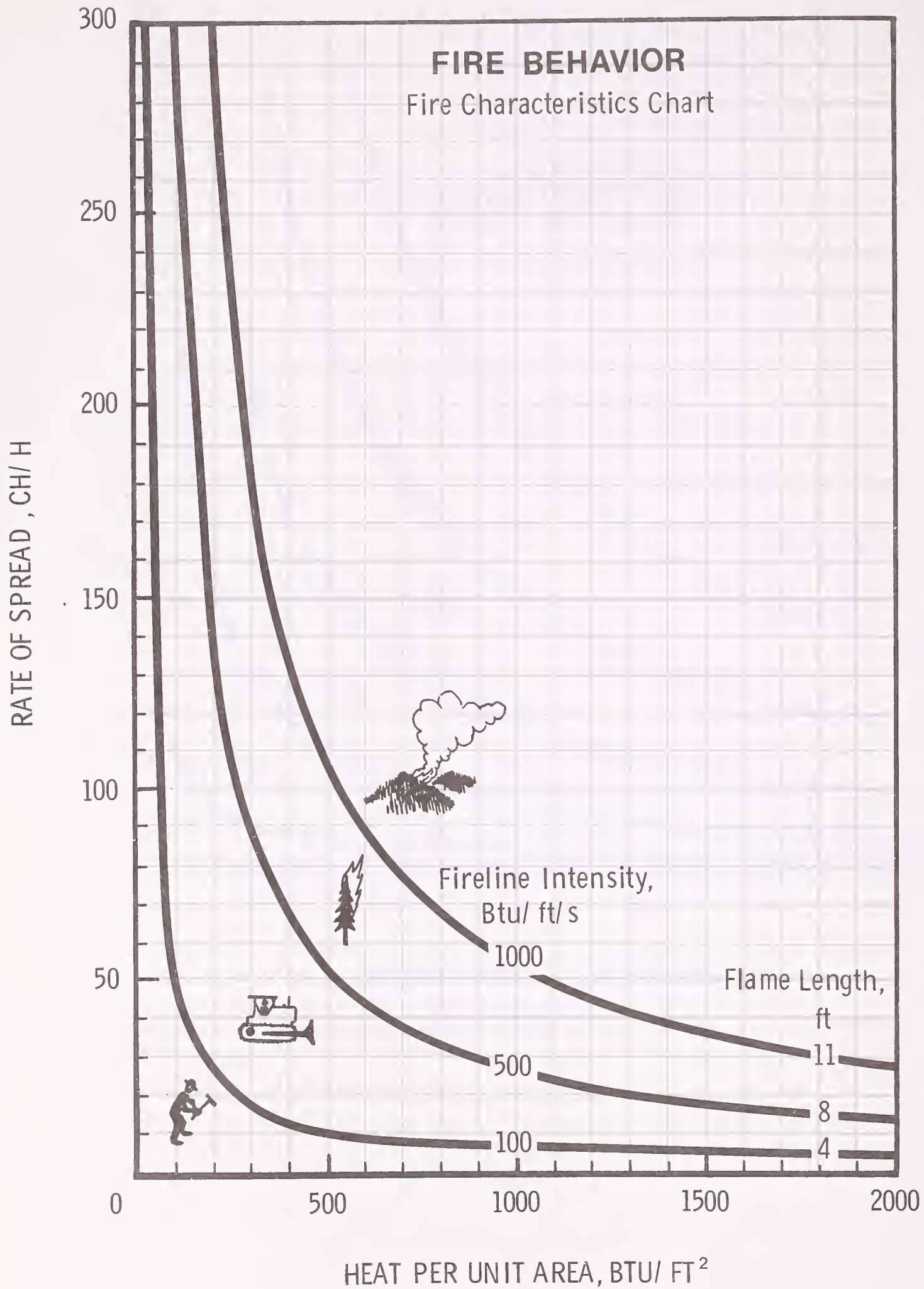
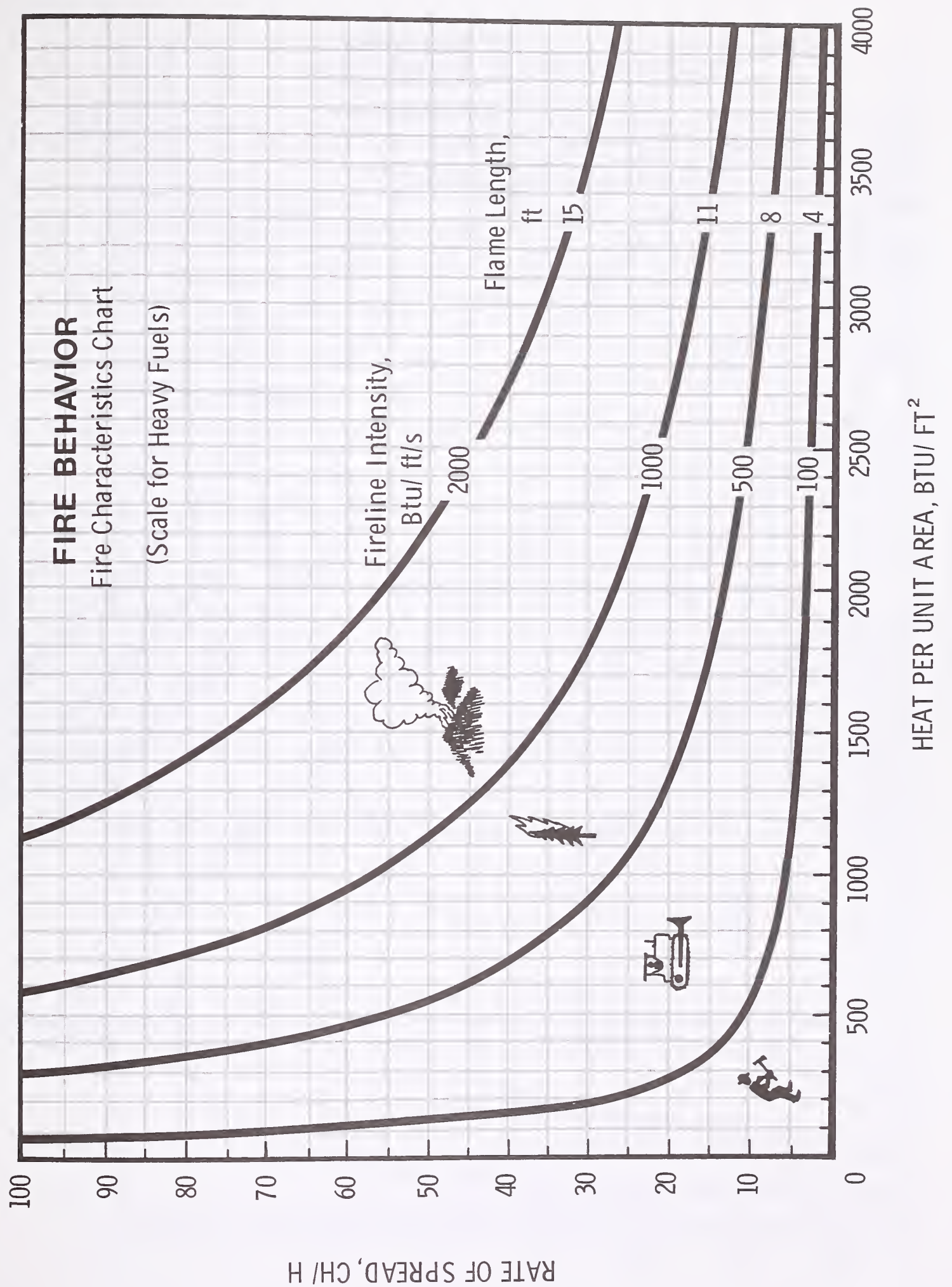


Figure 17.—Example of a custom NFDRS chart, where the BI lines correspond to manning class cutoff values. Manning classes are based on 1970-79 weather for Ninemile Ranger Station (241507).

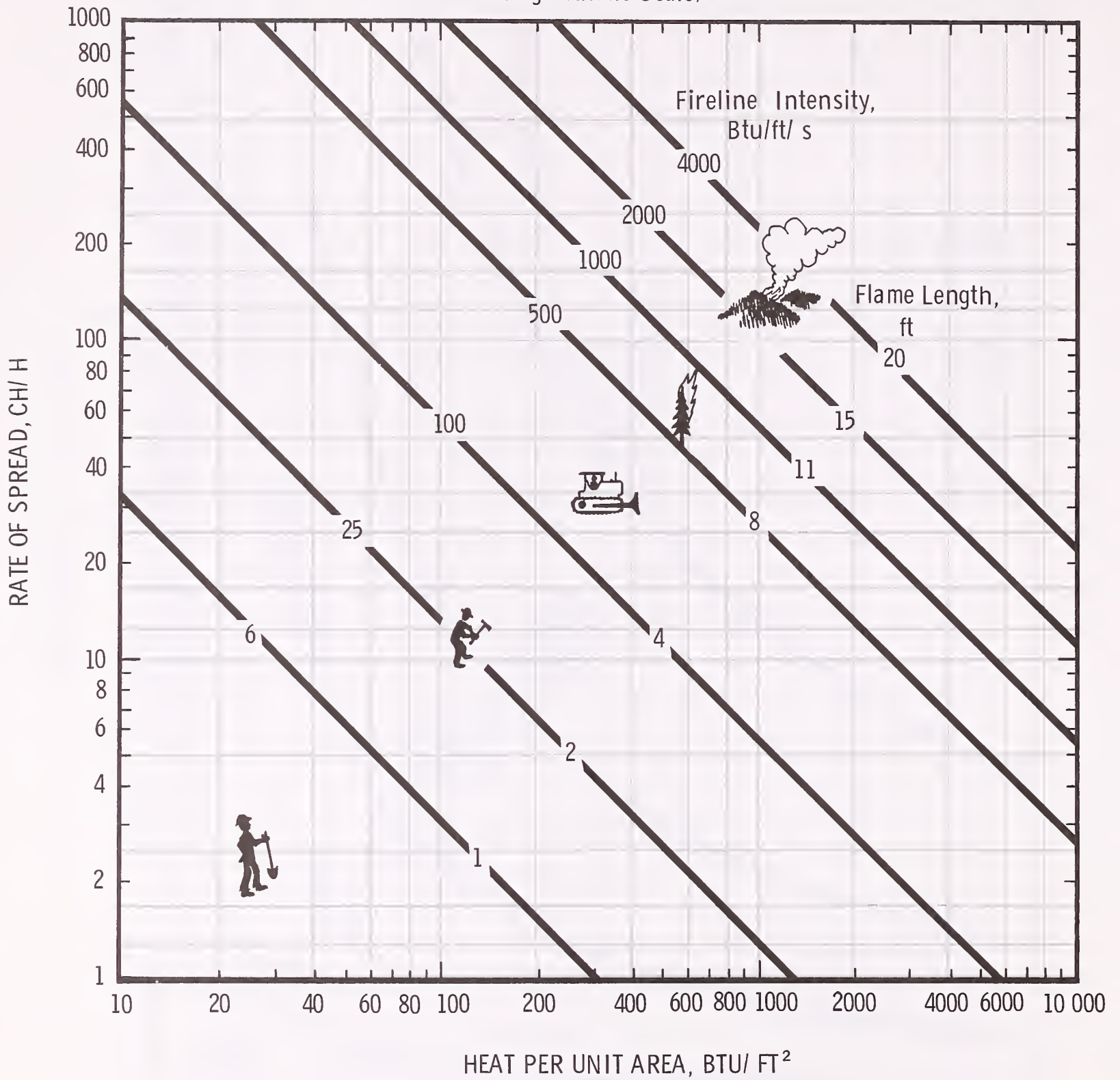
APPENDIX B
Fire Characteristics Charts
Suitable for Copying

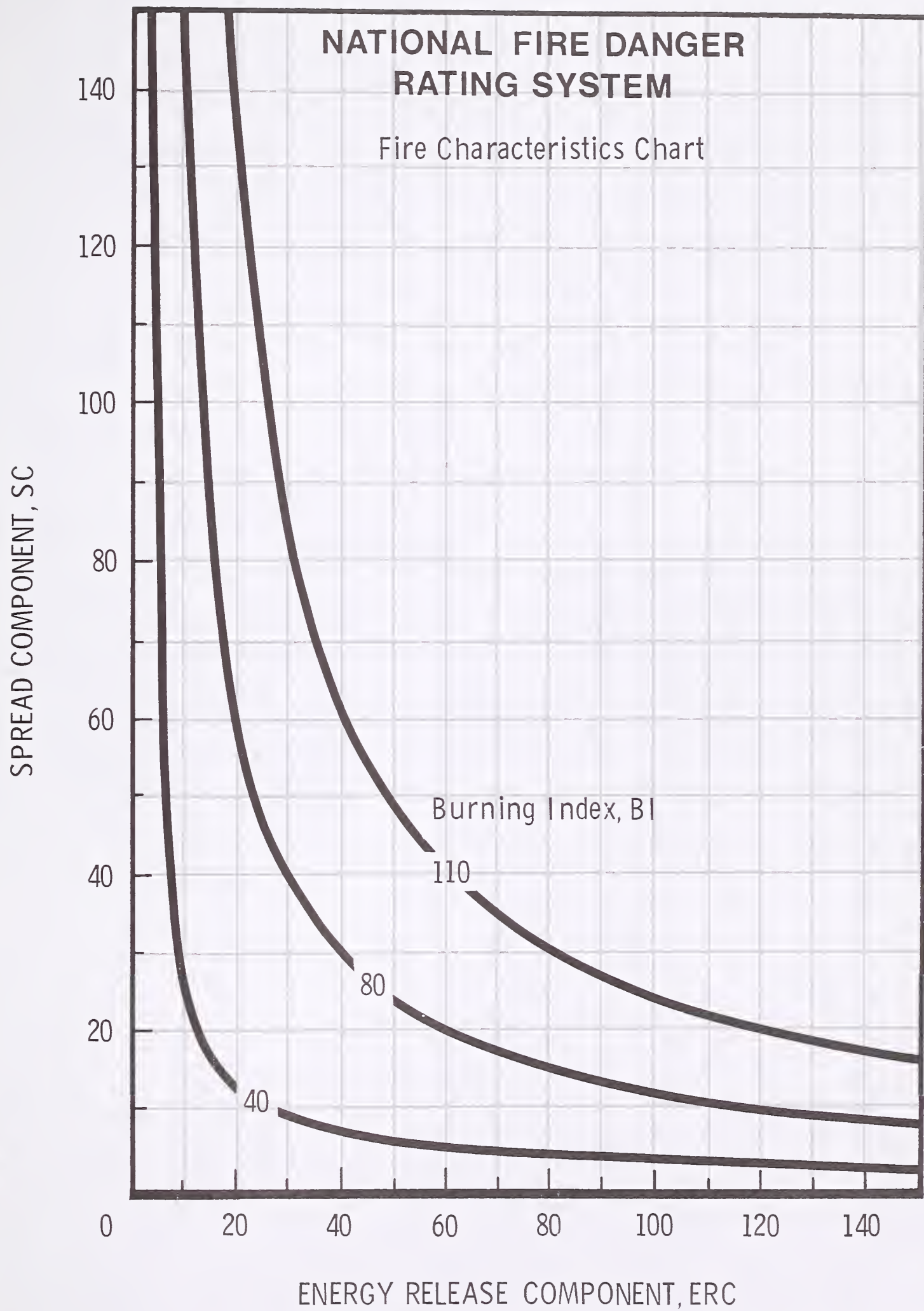




FIRE BEHAVIOR

Fire Characteristics Chart
(Logarithmic Scale)





Andrews, Patricia L.; Rothermel, Richard C. Charts for interpreting wildland fire behavior characteristics. Gen. Tech. Rep. INT-131. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 21 p.

The fire characteristics chart is proposed as a graphical method of presenting two primary characteristics of fire behavior—spread rate and intensity. Its primary use is communicating and interpreting either site-specific predictions of fire behavior or National Fire-Danger Rating System (NFDRS) indexes and components. Rate of spread, heat per unit area, flame length, and fireline intensity, are plotted on a fire behavior chart. Spread component, energy release component, and burning index are plotted on an NFDRS chart. Specific examples illustrate potential application.

KEYWORDS: fire behavior, fire spread, fire intensity, fire-danger rating, National Fire-Danger Rating System

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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